

A Novel approach for Fingerprint Minutiae Extraction by Ridge Tracing using Connected Component Analysis

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ABSTRACT:

Minutiae extraction is one of the most essential processes required for authentication and fingerprint analysis. There are many algorithms available for minutiae extraction, but most of them focus on authentication purpose. We proposed a new algorithm which is focused mainly for the purpose of the fingerprint analysis. However, this algorithm can be very well applied to the authentication purpose. Our proposed algorithm extracts the fingerprint features based on ridge (line) tracing using connected component analysis. This enables to find various parameters on each and every line which is essential for fingerprint analysis. For the preprocessing, the traditional methods are used which involves Enhancement, Binarization and thinning. In minutiae extraction process Connected Component Analysis is employed to identify the lines present in the captured fingerprint image. This novel method developed then extracts the minutiae points for each line. Apart from extracting the most vital minutiae points which are termination and bifurcation another unique minutiae called the enclosure has also been extracted giving way to study some peculiar characteristics from the fingerprint. The experiments were conducted on over 750 samples of our internal data base and Fingerprint Verification Competition (FVC) data base and good performance in minutiae extraction is achieved.

KEYWORDS: Minutiae extraction, lines, connected component analysis, enclosure

INTRODUCTION

Fingerprint images have been widely used in personal identification, forensic applications, risk analysis digital security and many other applications. Fingerprints are fully formed at about seven months of fetus development and finger ridge configurations do not change throughout the life of an individual except due to accidents such as bruises and cuts on the fingerprints [1]. This property makes fingerprints a very attractive biometric identifier.

A fingerprint is the reproduction of a fingerprint epidermis, produced when a finger is pressed against a smooth surface. The most evident structural characteristic of a fingerprint is pattern of interleaved ridges and valleys [1].

The fingerprint may be analyzed at the global level or local level. Global level represents overall attribute of finger. Major regions in global level

representations are left loop, right loop, delta and whorl. A local representation consists of different ridge characteristics called minutiae details.

Although 150 different possible ridge characteristics have been identified, the most common types are termination, bifurcation, lake, independent ridge, point or island, spur and crossover. A good quality fingerprint typically contains about 40-100 minutiae [2]. The two most prominent ridge characteristics called minutiae are ridge termination and ridge bifurcation [1].

In this proposed paper, the authors have come out with a novel minutiae extraction algorithm. This efficient algorithm identifies the most prominent ridge termination and ridge bifurcation.

Also the feature named as enclosure is identified. The enclosure is defined as the area enclosed by the two opposing forks (bifurcation) in a line.

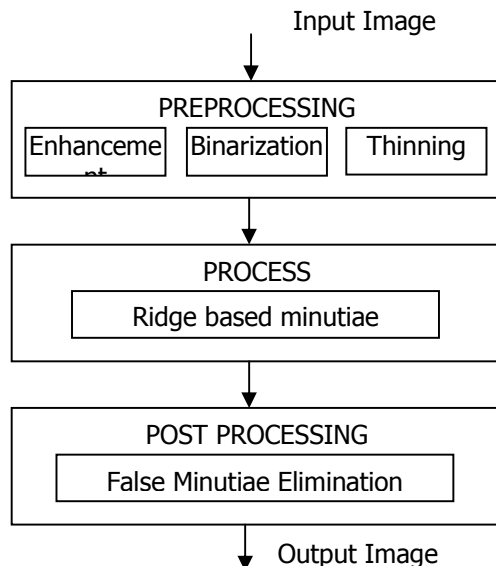


Fig. 1. Overview

Fig. 1 illustrates the overview of the different stages involved in minutiae extraction process.

Related work

Many fingerprint minutiae extraction algorithm have been proposed earlier. Most minutiae extraction algorithm attach a minutiae with three features x , y coordinates and direction [3]. Fingerprint identification / matching schemes are based on global features as well as comprehensive fingerprint features [1].

In fingerprint analysis, minutiae are more abstract than fingerprint pixels and a fingerprint can be represented by minutiae constrained with their properties and relations [4]. As the minutiae based techniques takes less memory and consumes less time for processing they are widely used in analysis and security.

Bhanu and Tan proposed a fingerprint matching based on matching indexing methods using minutiae-triplets [5]. The graph matching methods which locate minutiae and match their relative placement was proposed by Gold and Rangarajan [6].

Yuliang *et al.* in their paper "Fingerprint Matching Based on Global Comprehensive Similarity" proposed similarity based on minutiae simplex and the nearest neighborhood among minutiae and relationship between transformation and comprehensive similarity in terms of histogram [4]. Among the above and other existing fingerprint matching or analysis algorithm may provide a good results but sensitive to the quality of the fingerprint.

Thus for fingerprint matching or analysis, the reliable extraction of minutiae from the fingerprints irrespective of the quality of the image due to improper fingerprint position, variation in finger pressure on the scanner, oily skin, dry skin etc is essential. In our proposed technique, all true minutiae points of bifurcation, termination and the feature enclosure are identified.

This paper is organized as follows. In section 2, preprocessing is described. Section 3 explains the process of minutiae extraction using our proposed line tracing and connected component analysis. Also to remove the false minutiae post processing is applied.

Section 4 manifests the experiment results of our proposed algorithm. In section 5 we concluded the paper suggesting the future directions

PRE PROCESSING

The acquired Fingerprint images from scanners may be a degraded and /or corrupted due to many reasons. In practice, due to variations in impression conditions, skin conditions (aberrant formations of epidermal ridges of fingerprints, postnatal marks, occupational marks), ridge configuration, acquisition devices, and no cooperative attitude of subjects, etc., a significant percentage of acquired fingerprint images (approximately 10 percent according to our experience) is of poor quality [2].

Thus, for a reliable extraction of minutiae details, preprocessing techniques prior to minutiae extraction are essential. For minutiae extraction, the enhanced image is binarized first and then thinned to obtain the ridges of one pixel wide. In

the following section, preprocessing steps are demonstrated briefly.

Enhancement and Binarization

Image enhancement process greatly restores the missing information and removes spurious minutiae.

Image enhancement process consists of four main stages [7]. They are

- Normalization
- Image Orientation
- Image Estimation and
- Gabor filtering

In the process of normalization, the evaluation of moments represents a systematic method of shape analysis [8]. The evaluation of central moments, normalized central moments and moment invariants convey shape attributes and thus useful for object recognition.

Normalization does not change the clarity of the ridge and valley structures. If $I(i, j)$ denote the gray-level value at pixel (i, j) of the input image, the normalized gray level value at pixel (i, j) is defined as follows [2].

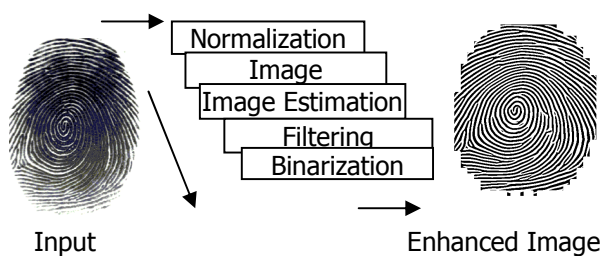


Fig. 2. Flow chart

Fig. 2. Flow chart showing the process of converting input image into enhanced binary image

$$N(i, j) = M_0 + \sqrt{\frac{V_0(I(i, j) - m)^2}{V}} \quad \text{If } I(i, j) > M, \quad (1)$$

$$= M_0 - \sqrt{\frac{V_0(I(i, j) - M)^2}{V}} \quad \text{Otherwise,} \quad (2)$$

Where M and V denote the estimated mean and variance of I respectively and M_0 and V_0 are the desired mean and variance values, respectively.

Image orientation is essential in enhancement process as the Gabor filtering stage relies on the local orientation to effectively enhance the fingerprint image. Number of methods has been proposed to estimate the orientation field of fingerprint images [9, 10].

The least mean square orientation estimation algorithm proposed by Lin Hong et al [2] is used to obtain the orientation.

The first step in the frequency estimation stage is to divide the image into blocks of size $w \times w$. The next step is to project the grey-level values of all the pixels located inside each block along a direction orthogonal to the local ridge orientation. This projection forms an almost sinusoidal-shape wave with the local minimum points corresponding to the ridges in the fingerprint.

Before performing Gabor filtering, it is reasonable to classify pixels into recoverable and unrecoverable region. This is achieved by mask generation. Other than Hong's algorithm [2] some other algorithms also proposed. As the Gabor filter has frequency selective and orientation selective properties, it effectively preserves the ridge structures while reducing the noise.

A two dimensional Gabor filter consists of a sinusoidal plane wave of a particular orientation and frequency, modulated by a Gaussian envelope [11]. An even symmetric Gabor filter in the spatial domain is defined as [12]. The application of Gabor filter G to obtain the enhanced image E is performed as follows.

$$E(i, j) = \sum_{u=-\frac{w_x}{2}}^{\frac{w_x}{2}} \sum_{v=-\frac{w_y}{2}}^{\frac{w_y}{2}} G(u, v; O(i, j), F(i, j)) N(i - u, j - v), \quad (3)$$

The convolution of a pixel (i, j) in the image requires the corresponding orientation value $O(i, j)$ and ridge frequency value $F(i, j)$ of that pixel. N is the normalized fingerprint image and w_x and w_y

are the width and height of the Gabor filter mask respectively.

The filter bandwidth is determined by the standard deviation parameters σ_x and σ_y and defined as

$$\sigma_x = K_x F(i, j) \quad (4)$$

$$\sigma_y = K_y F(i, j) \quad (5)$$

For binarization, the global threshold technique is effective in separating the ridges from the valleys. This improves the contrast between the ridges and valleys in a fingerprint image and facilitates the extraction of minutiae.

The binarization process involves examining the grey level value of each pixel in the enhanced image and if the value is greater than the global threshold then the pixels value is set to a binary value one; otherwise, it is set to zero.

Thinning

Thinning is a morphological operation that successively erodes away the foreground pixels until they are one pixel wide. It is a skeleton image of the given fingerprint image.

Many standard thinning algorithms [13-15] are available to perform the thinning operation. A standard thinning algorithm [14] is used, which performs the thinning operation using two sub iterations.

In first iteration, the image is divided into two distinct subfields in a checkerboard pattern, and each sub iteration deletes pixels p in a subfield when p is a contour pixel, $b(p) > 1$, and $XH(p) = 1$.

The second algorithm is a modification of thin to 8 connected skeletons and retains diagonal lines and 2×2 squares.

$$G1: XH(p) = 1$$

$$G2: 2 \leq \min \{n_1(p), n_2(p)\} \leq 3, \text{ where}$$

$$n_1(p) = \sum_{i=1}^4 x_{2k-1} V x_{2k} \quad (6)$$

and

$$n_2(p) = \sum_{i=1}^4 x_{2k} V x_{2k+1} \quad (7)$$

represent the number of 4 adjacent pairs of pixels in $N(p)$ containing one or two black pixels, and

$$G3: (x_2 V x_3 V x) \wedge x_1 = 0 \quad (8)$$

in the first iteration and 180° in the second.

This algorithm is accessible in MATLAB.

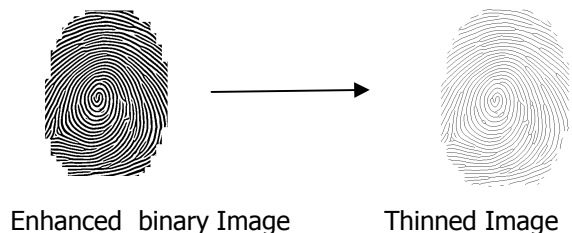


Fig. 3. Generation of thinned image from enhanced binary image

Fig 3. Thinned fingerprint image from the enhanced binary image. The enhanced image shown is the result of preprocessing of a given fingerprint image.

MINUTIAE EXTRACTION & POST PROCESSING

By using connected component analysis and the ridge tracing approach, all connected line segments with respect to all the pixels are determined. The minutiae extraction process is accomplished by block processing. In order to validate the minutiae, post processing is performed on the minutiae extracted image.

A connected component is the definition of a local neighborhood describing the connections between adjacent pixels. A region or an object is called connected when we can reach any pixel in the region by walking from one neighboring pixel to the next [8]. There are different neighborhood systems. In square grid, we have 4 and 8 neighborhood systems; in rectangular grid we can define 3 and 12 neighborhoods where the neighbors have either a common edge or common corner. In hexagonal grid, we can only define a 6 neighborhood because pixels which have a joint corner, but no joint edges. In three dimensions, 6, 18, and 26 neighborhoods are systems are defined.

Any set of pixels which is not separated by a boundary is called connected pixels. Each maximal region of connected pixels is called a connected component. The set of connected components partition an image into segments. Image

segmentation is a useful operation in many image processing applications.

Ridge Tracing

The steps involved in the proposed Algorithm for ridge based minutiae extraction is as follows:

1. Let T be the thinned binary image obtained after image enhancement.
2. Trace region boundaries in the thinned binary image T.
 - a. Run-length encode the input image.
 - b. Scan the runs, assigning preliminary labels and recording label equivalences in a local equivalence table.
 - c. Resolve the equivalence classes.
 - d. Relabel each region (line) with unique numbers based on the resolved such that each number in the labeled image represents a region.
3. Start loop i for numbers of lines identified
 - a. Initialize an image B of the same size as the fingerprint image being processed with 0's.
 - b. Set the pixel values corresponding to the ith region as 1's.
 - c. Find indices (r, c) of nonzero elements.
 - d. Start another loop j for number of 1's present in image B.
 - i. Let x be equal to r(j) and y be equal to c(j)
 - ii. Create a 3x3 square mask S around the (x,y) pixel
 - iii. If center pixel is equal to 1, calculate the sum of all the elements present in S excluding the centre element.
 - e. If the sum corresponds to 1 then mark the centre pixel co-ordinate as termination point and if the sum corresponds to 3 then mark the centre pixel co-ordinate as bifurcation point.
 - f. End loop j.
4. Also the minutia called enclosure for each line is identified by tracing the region boundaries (Fig. 5.).
5. If an enclosed area is identified, then the corresponding boundary pixels are marked enclosure.

6. End loop i.
7. In Post processing stage the false and non-vital minutiae can be eliminated. Create morphological disk-shaped structuring element SE of radius $R = 3$.
8. Erode the mask of the fingerprint area located during the image enhancement process [16].
9. Now check whether the identified minutiae points are present within the new mask created in the previous step.
10. If the points lie beyond the mask then those Minutiae points can be discarded because those will not mostly be the actual termination or bifurcation but formed due the end of the fingerprint acquired. (fig. 6.)

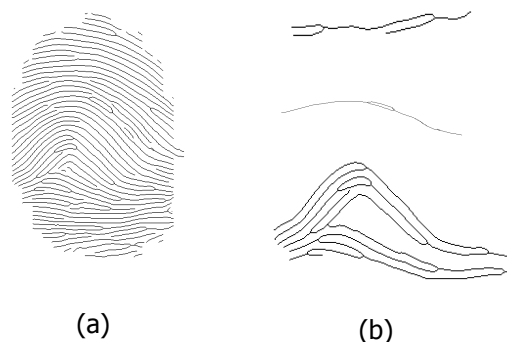


Fig 4. (a) Thinned image (b) Some of the regions (labeled line) of the input image

Fig 4. Extraction of the line objects from the thinned input image

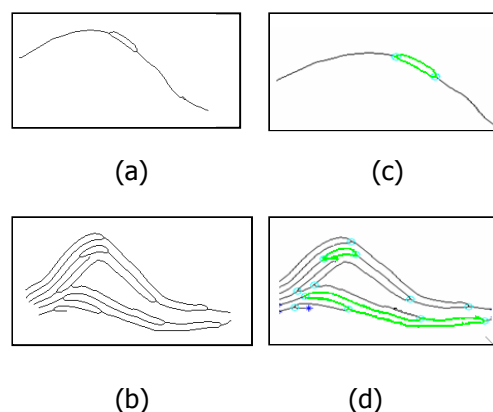


Fig. 5. (a) and (b) connected objects; (c) and (d) enclosure identified in connected objects;

Fig. 5. Identified enclosures (fingerprint feature) from the line objects of a fingerprint image.

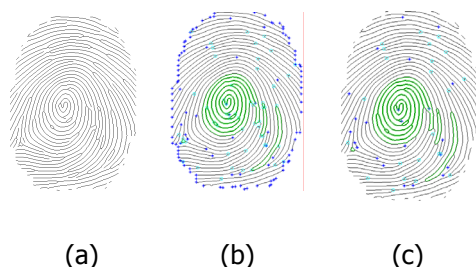


Fig. 6. (a) Input image (b) Image after processing (c) Output Image after post processing

Fig 6. Three fingerprint features (Termination, Bifurcation and Enclosure) identified from the given input image are shown.

EXPERIMENTAL RESULTS

We restricted ourselves to a set of 750 fingerprint images whose results were compared quantitatively by a human operator. The fingerprint images used here were obtained from the FVC2000 (Fingerprint Verification Competition) [17], FVC2002 [18], and FVC 2004 [19].


Moreover, we personally collected a small data base using fmgkey Hamster II scanner manufactured by Nitgen biometric solution, Korea [20]. Subsequently, we will refer to this as the "internal data base". The size of the FVC images is 640 X 480. The Hamster II database contains 270 images of 27 individuals. The size of the image is 260 x 300 with resolution 500 dpi.

These fingerprints are collected from various peoples irrespective of gender and age. When these fingerprints were captured, no restrictions on the position and orientations were imposed and fingers of different kinds (e.g. fingers with creases and smudges, dry and wet fingers etc.) were scanned. Other large public domain database is the National Institute of Standards Technology (NIST) collections.

The fingerprint images in the database vary in quality. More than 98 % of the Hamster II fingerprint images captured with satisfactory quality, whereas about 90% of the FVC fingerprint images are of good quality.

Our algorithm has been developed, debugged and tested on a PC with a Pentium 4 CPU (2.40 GHz), RAM of 512 MB and using the MATLAB 7.1 image processing tool.

Table 1: Percentage of correctness of minutiae extraction by proposed method

	No. of Samples	% of correctness
FVC 2000	160	91.25
FVC 2002	160	92.75
FVC 2004	200	94.00
Internal database	230	98.00
Tot	750	94.00

After testing, it is found that the proposed line based method gives accurate results for 91.85 % of the total fingerprint samples. The false minutiae extraction is found more in the case of DB3 of FVC 2000 (only 82% of the outputs are matched with human expert) and FVC 2002.

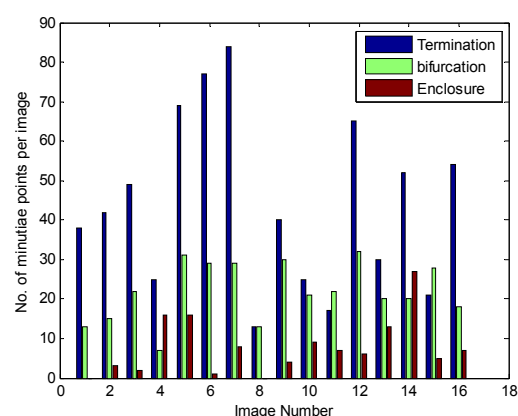


Fig. 7 Bar graph

Fig. 7 demonstrates the statistical view of the number of terminations, bifurcations and enclosure. The blue color represents the termination, green color represents the bifurcation and the brown color represents the enclosure

From table 2 it is evident that fingerprints may or may not contain the enclosure. This valid information may be useful in authentication and fingerprint analysis. Minutiae details are shown as a bar graph in figure.7

Our proposed algorithm identifies all the connected line objects as lines and then the minutiae are extracted from each line. In one cycle all the line objects are determined. Only few line objects and its extracted minutiae are tabulated. Thus, the usefulness of the proposed algorithm in digital security and fingerprint analysis is validated.

In table 3, results of two images showing the line objects with three features of a fingerprint is shown. Input images are randomly chosen the internal database and from the FVC data base. Each input image is selected randomly with various qualities.

Table 2: Results of randomly selected fingerprints





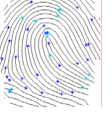
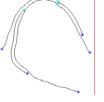
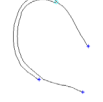
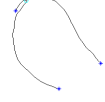
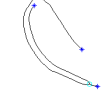

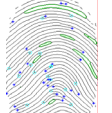
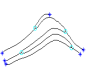
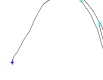

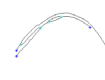
Input Image		No.of Lines	Minutiae Observation obtained using our line based method		
					
Fingkey Hamster II	1002 S_8	47	38	13	0
	102_1	44	42	15	3
	106_7	51	49	22	2
	107_9	40	25	7	16
FVC 2000	DB1 108_8	45	69	31	16
	DB2 104_8	41	77	29	1
	DB3 103_8	72	84	29	8
	DB4 101-8	39	13	13	0
FVC 2002	DB1 104_7	46	40	30	4
	DB2 104_6	41	25	21	9
	DB3 109_5	35	17	22	7
	DB4 109_6	62	65	32	6
FVC 2004	DB1 100_2	51	30	20	13
	DB2 12_8	65	52	20	27
	DB3 23_6	36	21	28	5
	DB4 3_6	38	54	18	7

Table 3: Results of minutiae extraction using proposed line based approach

Hamster II 1002 S_8	
Input Image 	Output Image 
Few samples of line objects and the identified minutiae	
	
	
FVC 2004 DB1 100_2	
Input Image 	Output Image 
Few samples of line objects and the identified minutiae	
	
	

CONCLUSION AND FUTURE WORK

An Efficient line based approach for minutiae extraction of a large variety of fingerprint images has been proposed in this paper. Experiments were conducted for different types / quality of images to provide unique and vital information about the fingerprint. This method extracts the minutiae points based on each line identified.

Another feature called the enclosure which is the area enclosed between two bifurcation in the same line has also been identified. By setting additional rules in the algorithm, this novel approach can detect any required fingerprint information.

However, we have limited our study with ridge termination, bifurcation and enclosure. This method has been found to be efficient in time as well as accuracy which give way to a wide variety of applications such as digital identity management, digital forensics, information security, risk analysis etc.

Further work can be focused on removing the false or unwanted lines and identifying the useful line from the total line and thereby reducing the processing time and memory used which is very vital when implemented on a DSP or a FPGA. Also the same work can be extended for extracting the other minutiae such as spur, crossover, dot, snort ridge, bridge etc.

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